Thermal and Mechanical Properties of Electron Beam Welded and Heat-Treated Niobium for Tesla

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Abstract:

The design accelerating gradient for Tesla SRF cavities is 25 MV/m. For acheiving such high accelerating gradients both the field emission and thermal quench limitations have to be eliminated. Post purification of the niobium sheets, cells or the completed cavities is likely to achieve the required gradients. However, such treatments are bound to reduce the mechanical properties of the accelerating structure. In this paper thermal and mechanical properties of electron beam welded and heat treated high RRR niobium are presented.

Introduction:

Low temperature mechanical properties of as-received reactor grade (Cabot) and high RRR Niobium (Teledyne Wah Chang, Heraeus and Fansteel) have been reported by us in the past[1]. More detailed cryogenic mechanical properties of as-received and post-purified Teledyne and Fansteel Niobium with RRR of over 250 and material thickness of 3.175 mm were presented at the recent International Cryogenic Material Conference in Albuquerque during July 1993[2]. Since RRR and mechanical properties seem to vary from batch to batch as well as on the thickness of the material, we have recently studied the thermal and mechanical properties of Tesla niobium. The samples were provided by the Cornell group. The thickness of these samples was 1.59 mm and the as-received RRR was 400. In the following both the thermal and mechanical properties of as-received and post-purified niobium is presented.

Thermal Conductivity:

The thermal conductivity measurements were carried out in the conventional way[3]. Matched Southampton Miniature Diode Thermometers (SMDT) were used for measuring the temperature difference across the niobium samples. Figure 1 shows the thermal conductivity of Tesla Nb as a function of temperature for as-received, one side welded (not full penetration) with electron beam and purified at 1400° C with Ti for four hours and both sides welded (full penetration) with electron beam and purified at 1400° C with Ti for four hours. It is apparent that the RRR of the one side electron beam welded sample improves by a factor of 3.4, where as both the sides welded sample improved only by a factor of 2.7 after post-purification.

Table 1 summarizes the RRR values of Nb. It appears that the quality of vacuum in the electron beam welder plays an important role in maintaining the starting RRR value; the sample E-beam welded at 10^{-4} torr (RRR=158) degrades more than the sample welded at 10^{-5} torr (RRR=198) in comparison to the as-received RRR value of 228. The post-purified RRR value of the production weld sample is lower than the only post-purified sample confirming that during the welding process the Nb RRR degrades. The thinner sample (thickness=1.58 mm) RRR seem to improve more than the thicker one (thickness=3.17 mm).

Mechanical Properties:

The details of the sample preparation and testing were discussed elsewhere[2]. Figures 2 and 3 present the stress-strain curves of the Tesla Nb at 293 K and 4.2 K respectively. The as-received sample has a linear stress region up to 125 MPa, indicating elastic deformation. The post-purified Nb sample region has the linearity up to a stress value of about 50 MPa, while the welded and the post-purified sample further deteriorates with practically no linear region indicating that it would plastically deform even under small stress.

Table 2 summarizes the tensile properties of the Tesla Nb samples. It can be seen that the tensile properties; 0.2 % offset yield strength (YS), ultimate tensile strength (TS) and percent of elongation of the welded and post-purified sample deteriorate more than that of the just purified sample in comparison to the as-received sample. As can be expected the yield and tensile strength of Nb improves considerably at 4.2 K. Also the ductility of the post-purified and welded and post-purified Nb samples seem to improve at 4.2 K.

Conclusions:

The quality of vacuum in an electron beam welding machine determines the extent of degradation in the RRR value of the as-received Nb. The mechanical properties of Nb deteriorate after post purification as well as welding. Welding and post-purification degrade the mechanical properties of Nb drastically.

Acknowledgments:

The authors would like to acknowledge the skillful electron beam welding of the samples by John Brawley.

This work was supported by US DOE Contract No. DE-AC05-84ER40150.

References:

1. P. Kneisel et. al, "Proc. of the Conf. Electron Beam Melting and Refining State of the Art 1990," R. Bakish ed.: Baskish Materials Corporation, Englewood (1990).

2. M. G. Rao and P. Kneisel, Presented at the 1993 International Cryogenic Materials Confernce, Albuquerque, July 1993.

3. M. G. Rao and P. Kneisel, "Thermal Conductivity Measurements on Electrodeposited Copper in the Temperature Range between 2 K and 40 K," CEBAF TN #93-042.

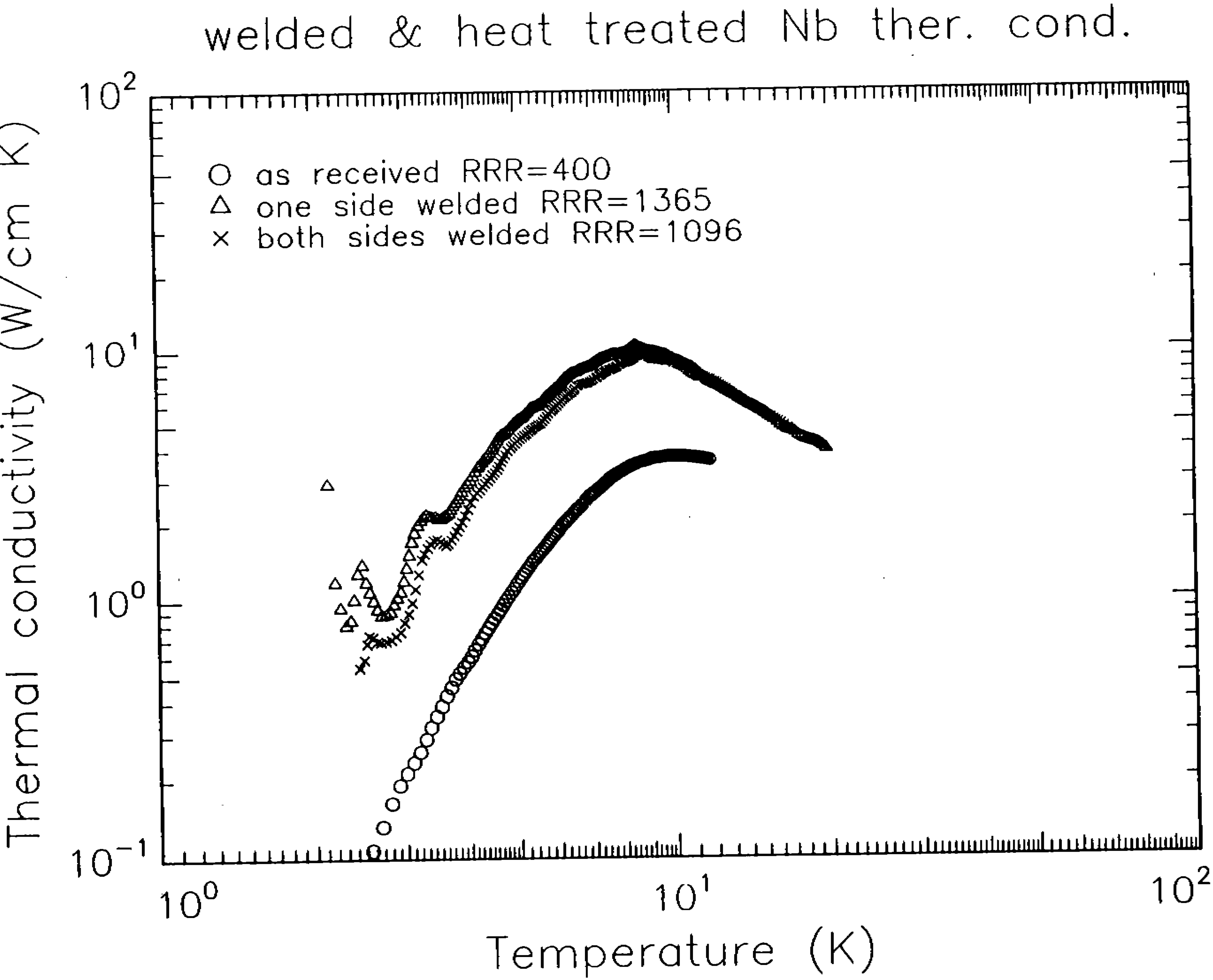
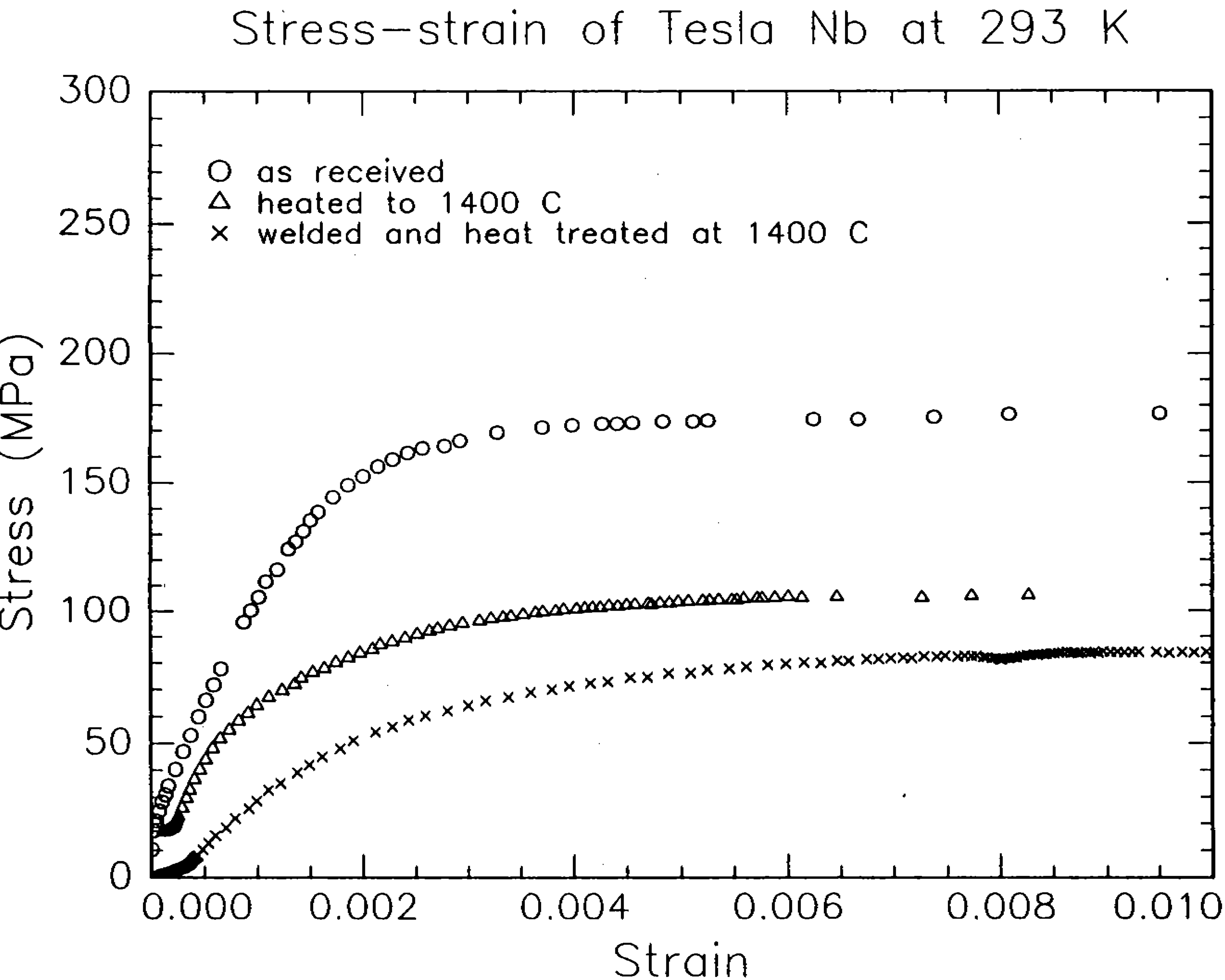

welded & heat treated Nb ther. cond.
Thermal conductivity (W/cm K)
Temperature (K)
O as received RRR=400
Δ one side welded RRR=1365
× both sides welded RRR=1096
10^{2}
10^{1}
10^{0}
10^{-1}
10^{0}
10^{1}
10^{2}

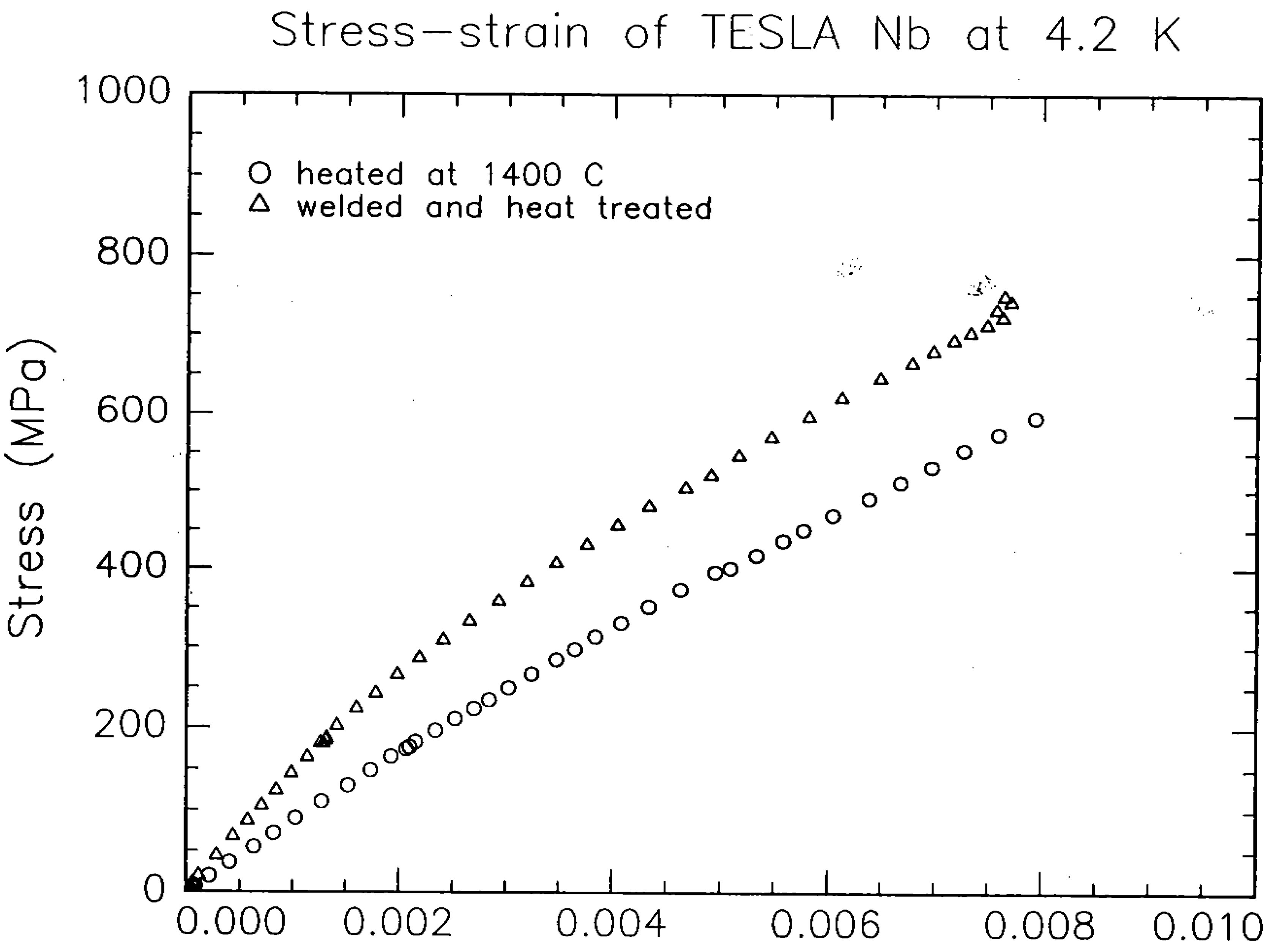
TABLE 1

SUMMARY OF Nb RRR

Niobium	Thickness	Status of the Sample	RRR
Heraeus	1.58	As received	228
Heraeus	1.58	E beam heated at 10^{-5} Torr	198
Heraeus	1.58	E beam heated at 10^{-6} Torr	158
Fansteel	3.17	As received	~300
Fansteel	3.17	Production weld purfied	596
Fansteel	3.17	Post purified	816
Tesla	1.58	As received	400
Tesla	1.58	One side beam heated and purified	1365
Tesla	1.58	Both sides E beam heated and purified	1096



Stress-strain of Tesla Nb at 293 K
as received
heated to 1400 C
welded and heat treated at 1400 C
Stress (MPa)
Strain
300
250
200
150
100
50
0
0.000
0.002
0.004
0.006
0.008
0.010



Stress-strain of TESLA Nb at 4.2 K
heated at 1400 C
welded and heat treated
Stress (MPa)
0
200
400
600
800
1000
0.000
0.002
0.004
0.006
0.008
0.010

TABLE 2
SUMMARY OF TENSILE PROPERTIES OF THE TESLA Nb†
(Thickness = 1.59 mm)

Niobium	At 293K YS (MPa)	At 293K TS (MPa)	% Elongation	At 4.2K YS (MPa)	At 4.2K TS (MPa)	% Elongation
As received	165	186	42	896	903	>1
Heat treated with Ti at 1400° for 4 h	102	128	30.2	__*	779	15.2
Welded & heat treated with Ti at 1400° C for 4 h	79	115	25.6	__*	807	6.6

†Samples were provide by Cornell University

*Serration started before reaching 0.2% offset yield

gms[Myneni/Correspondence]Table,Tensile Properties of TESLA Nb,October 19, 1993